IMMERSIVE SIMULATION OF COMPLEX SOCIAL ENVIRONMENTS

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ABSTRACT

This paper describes the development of an immersive multi-agent training simulation system that applies culturally realistic and highly variable behavior modeling in complex and critical decision-oriented social scenarios patterned after actual critical incidents gathered from the field. The simulation employs an experiential model of cultural and cognitive behavior to drive the actions of agents (e.g., simulated members of the civilian population) that interact, producing variable group behavior. In the proposed model, an agent's perception of an event is based on individual experience, personality (effectors), shared experiences, and agreement (belief) with other members of the population. Within the variable environment, discrete training tasks are evaluated by: 1) the ability to complete tasks within constrained parameters of the training objective; and 2) resultant effect on the population.

1. INTRODUCTION

The study of populations using variable agent-based modeling has been effective in describing complex events that can often be hard to predict. Cultural modeling based on norms, conformity, and social influence has been studied since the early 1900s, and relationships within social networks have been found to exercise significant influence on decision-making processes. (Kennedy, 2001) To understand the nature of diverse cultural interactions, one must examine individual cognitive and affective responses, and how those responses are transmitted and accepted in the social network. Social impact theory predicts that, as strength and nearness amplify within a group, so will conformity. Latane discusses the importance of the group and the conformance of individuals to the group's normative pressures. (Latane and L'Herrou, 1996)

How societal members agree upon some experience is based on a number of internal states (beliefs) and a number of external effectors (e.g., social values, history). Ultimately, some agreement as to what has happened must first be developed and then internalized. The agreement is prone to interpretation, bias, and misinformation, which create erroneous versions of what has transpired. Dawkins presents a model for describing knowledge evolution within a social group through interpersonal exchange (memetics). (Dawkins, 1987) Where genetic duplication tends to be precise (and mutation is highly irregular), cultural evolution is prone to a number of elements that can quickly adapt itself to its surroundings. (Gu, 2008) Dennett notes that memetic knowledge is prone to high variability and differing from physical genetics; cultural genetics can be shared interspecies (from different cultural subgroups/factions) and inter-generational. (Dennett, 1995)

Variability models explaining the evolution of social knowledge—well researched in social complexity—do not have a strong foundation in the application to virtual training systems. Yang and Tan discussed a set of mechanisms that describes variation in belief through genetics with a fidelity value for describing correctness of information (Yang and Tan, 2006), but with minimal discussion of perception and communication, and value in training exercises. Mariano and Correia discuss an agent agreement model with a multiple Pareto Optimal strategy approach, but do not make any assumption about the truthfulness of the agent. (Mariano and Correia, 2002)

We propose a model of passing, sharing, and evolving knowledge within the group structure as a type of cultural genetics (evolution). The proposed model is a form of adaptable and evolving genetics where events and the sharing of information about those events (communication, perception) create beliefs about the state of affairs in a society. An agent's experience of events is communicated to other participants (agents or subjects) through language and gesture, and is prone to uncertainty, misperception, and misrepresentation. The model also considers the nature of immersive environments that provide a mechanism for a subject to interact directly with a multi-agent system and effect change within. We propose three primary design principles: 1) experiences shared can be passed through the social network and exhibit filtering based on internal and social bias, 2) events that shape experiences are prone to multi-order effects so that outcomes are not easily determined, and 3) discrete training exercises should occur in such varied environments to understand the nature of order and equilibriums in volatile areas.

1.1 Constructing Socially Dynamic Agents

In developing an agent-based communication simulation model, we employ a cultural and cognitive behavior model that drives the actions of individual agents (e.g., simulated members of the civilian population) producing variable group behavior. The

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SDEM mechanism design contains: 1) an input (perception) state, which analyzes incoming data from the environment either through some sensory mode (e.g., visual or auditory) or through communication with other agents, 2) internal (personality characteristics, memories, goals) and external influencing factors (societal beliefs and constraints) that shape the acceptance of some knowledge, 3) a memory model designed to encode and store discrete knowledge data, 4) a filtering mechanism that allows the agent to analyze and prioritize the validity of that knowledge either through internal beliefs, previous knowledge, or collaborative agreement, and 5) a means to communicate knowledge in some natural manner (verbal communication, gestures).

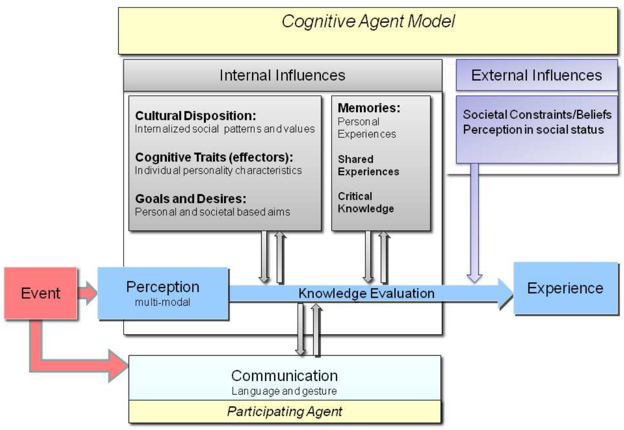

Fig. 1: Socially Dynamic Agent Model

Perception: The perception model mimics the common input modalities (senses) that help with the initial sense-making process. The agent collects first order knowledge of the environment through audio (volume, frequency, spatial location), visual (line of sight and view angle), and other modal cues (e.g., perception of motion). First order knowledge of the environment can aid in spatial understanding of the environment (e.g., *detonation <x> happened at some location*), evaluate goal-based behavior (*my safest exit may be at <x>*), and assist in social evaluation (I *want to participate in a collective conversation happening at <x>*). Perceptual input can also act as important stressor cues within the environment (e.g., detonation sound will help localize danger area) and to a degree, the participant (man-in-the-loop) will also share in these perceptual experiences.

Internal Influences: Agents contain several internal influences/effectors and some predisposed beliefs (memory) that define a type of simulated personality. Effectors modify and shape the experience based on internal psychological characteristics of the agent. Cognitive values affect individual perception and decisions and, in turn, affect collective perceptions and actions. The internal influencing factors contain a weighted value for likelihood of change or deviation from the mean value, and may be highly susceptible or resistant to change from external conditions. For example, certain effector variables (e.g., panic) change quickly over a short period of time, where others (e.g., nationalism, a much more immutable characteristic) will not deviate as easily.

Memory Model (the Experience): The memory model stores all events as experiential knowledge (personal experiences) and second order (shared) experiences with other agents. An experience is a compounded construct whose basis is a discrete event in time, a perception of the event, and an emotion tied to that event (Figure 2). The experience is highly subjective in nature and in and of itself may not be accurate or validated. The model is primarily a synthetic interpretation of what has happened and can be highly variable.

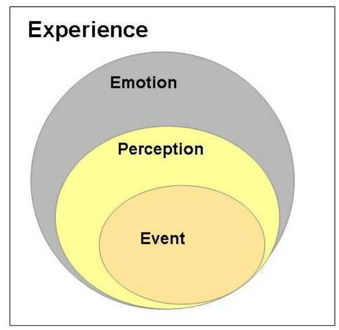

Fig. 2: Experience Model

The outward circles in the experience model represent the likelihood of non-valid information adding to the interpretation of the experience. Thus, as the event is perceived and an emotional element is added to that perception, the experience becomes more open to interpretation. Experiences are personal in nature but can be shared. The resultant shared experience will be filtered through the receiving agent's internal influences and will most likely carry some of the original understanding of the perception and the emotion tied to it. The method of communicating and personalizing an experience is explained below.

Engagements and Decision-Making: Agents of similar predispositions are designed to interact in a continual state-sharing mode. In this mode, they are most likely to greet, express domain knowledge, share concerns, and discuss feelings about events. In the engagement mode, agents must first decide whether to cooperate or not with other agents. In our method, cooperation is predicated on an individual's strategic desire to maintain equilibrium in himself (first), his immediate family (second), and faction (third). Agents decide their level of cooperation with other agents using a *cooperation* function. Decision-making cooperation function has roots in negotiation protocol design. At a personal level, agent decisions are based on *Individual Rationality* where decisions offer at least as much utility

as not participating in the protocol. *Individual Rationality* is represented as function $\alpha = (P, K, I, Id, R, C)$ where:

- *P* is personality (cognitive) traits
- *K* is perceptual (modal) knowledge
- *I* is observable influencing agents
- *Id* is immediate danger
- *R* is personal relationship with agent
- *C* is general likelihood to cooperate

The model uses a set of convergence functions, based on the Wetzel and Insko (1982) model (agents are attracted to their ideal agents), and homophily models (agents are attracted to like-minded agents) to determine likely candidates for communication. We use a closest match formula that matches faction, internal effectors, and physical influence sphere, with each effector value assigned a weighted level of importance. Weight is also applied to similar faction and an agent's sphere of influence. Several other context-specific factors also drive the attraction of agents to other agents, including visual perception (line of sight, proximity), likely collaborative goals, and beliefs about the other individual's willingness to listen.

Designing group-level decision-making will place emphasis on balancing social order with personal goals. We use negotiation protocols are designed to mimic a modeled social group's propensity towards collaboration and cooperation.

- *Social Welfare*: Ensures decisions are made that maximize the utility of both parties in collaboration
- *Pareto Improvement:* An agent's decision makes him better off without making any other individual worse off
- *Individual Rationality*: An agent chooses individual choice or protocol which he believes is in the best interest of cooperating parties
- *Stability (Equilibrium)*: Agents make decisions based on maintaining an equilibrium in the society

Communications: Communications are verbal and non-verbal (gestures, actions) means of sharing information, feelings, and experiences between agents. If the decision to interact is established, either a conversation takes place or some form of action occurs. In a conversation, knowledge sharing occurs as two or more agents (or an immersive player) discuss and share information about an event/group of events. An event may be familiar to only one agent, where the receiving agent learns second-hand knowledge about the occurrence. The event may also be familiar to both and the agents may share their personal experiences about it. These experiences are shared through language and gestures.

Language is a natural means for members of a social network to describe domain information, express memories, and their overall disposition. Language transmissions are passed directly between agent communicators and are intended to: 1) mimic natural responses between agents (and trainee), and 2) express the communicated experience in a natural syntactical way. The developed language model and schema definition uses informing statements to convey information between agents and the immersed trainee. The agent's knowledge is encoded as a communication message and passed to the receiving agent as a set of script tags. The schema contains a set of definitions for speech acts that are greeting, informing (state information), questioning, requesting, and labeling. In a positive non-verbal engagement, actions such as waving, hand-holding, or walking together may occur, where in a negative non-verbal exchange, the actions may be taunting, rock-throwing, or weapon firing. The language syntax describes both verbal (text and audio) and non-verbal (gestures, shared knowledge) exchange. In the example given in Figure 3, the bracketed tag represents information that must be retrieved by the speaker to express a full thought, including statements, knowledge, and physical gestures and acts.

```
Type: Greeting: Greet
[n1]<GreetingResponse> I am <Hostility>
today, have you noticed anyone unfamiliar
to you? <CounterResponse:
RespondToMember[Usage:Hostility],…>

Type: RespondToMember: Informing
[n1] :<ObserveArea>, <Gesture>
<EvaluateUnfamiliarAgents> I <likelihood>
saw <AgentX> speaking with <AgentY> and I…
```

Fig. 3: Schema Syntax

The dialog in the above discourse begins with a *Greet* speech act (<*Greeting*>) and a *Questioning* statement, where the agent is looking for new information to understand his domain. In the response (<*RespondToMember*>), the agent aids in locating unfamiliar or suspicious agents. Each schema tag represents a knowledge specification that must be (or has been) encoded in the framework. The syntax "Usage:" expresses a variable that decides the next branching response:

```
R(n)= [n1]:<ObserveArea>, <Gesture>…
```

The value *n1* states which of the n^{th} *Informing* speech acts is used based on [`Usage:Hostility`]. Any number of additional statements can be applied to the *R(n)* informing statement to create a varying set of responses.

Encoding Knowledge in Syntax (Meme): Notational tags within the schema definition specify knowledge that will be retrieved from either the sender or receiver and passed as data between the conversers. These elements of data that describe fragments of knowledge, the meme (from Dawkin's (1989) term "memes"), is any type of discrete information that can be expressed, stored, and shared between agents and stored as an artificial memory. In our model, memetic data is polled directly from the language syntax (e.g., *AgentSender <Knowledge of Event>)* and can be used to piece together compound thoughts (complex sentences) into more complete meanings for the agent. Note in the Figure 3 example, the full conversation only makes sense to the receiving agent when each syntax piece is strung together in a logical response (e.g., *I may have seen <Agent Y> talk to <Agent X> outside his faction and <I am very concerned>).*

Agreements and Consensus: Decisions as to how the agent will accept data as valid are based on a model of agreement between participants (Figure 4). The agreement is a personal expression of belief attached to a particular experience as the basis for how information is both stored as a memory and transmitted to other virtual agents. Similar to a child's game of telephone, an agent is not a perfect medium for communication. When a singular event occurs at some time in the simulation, each agent will accept what has happened, reject it, or come to some conclusion based on what knowledge has been acquired. This knowledge is then shared through both direct communication in a syntactical manner ("I saw some event and the culprit of this event"), and alternate means of communication, such as physical gestures or actions.

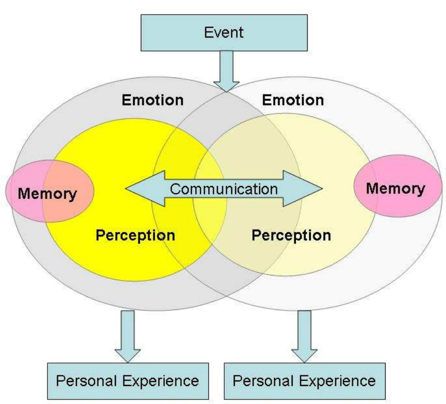

Fig. 4: Sharing Knowledge through Agreement

Figure 4 illustrates how an event shared by two agents is discussed, and a personal experience comes from the encounter. The opaqueness of the shapes represents the strength of conviction (certainty) the agent expresses about the event. Note recollection and perception of the incident may be unclear. Also the emotional component tied to the event plays a role in how the event is perceived. For example, discrete emotional elements may be applied to the language structure. ("The <event>weapon fire<event> made me <emotion>very nervous<emotion>"). The final experiences between two conversing agents are shaped by the equation:

$$A(n) = (\alpha, \mu, \nu, \tau)$$

The agreed-upon event $A(n)$ is a function of several influencing factors from the alternate agent, including memory recall of the event $\boldsymbol{\alpha}$, previous consensus of the event $\boldsymbol{\mu}$, influencing effectors (social learning models) $\boldsymbol{\nu}$, and *first-hand* knowledge or perception of the event $\boldsymbol{\tau}$. The final agreement function provides an experience memory and a potential change to the agent's effector (personality) values.

Knowledge Mutation: Knowledge transferred between agents maintains a fitness value based on *Unintentional Misperception*—data that is not fully available to the agent, and *Intentional Misperception*—information that is available to the agent but is intentionally modified/obfuscated with the intention of spreading misinformation. Intentional Misrepresentation can be used as a strategy (agent or subject) to shift or transmute knowledge as necessary.

2. APPLICATION IN IMMERSIVE ENVIRONMENTS

The approach thus far has primarily been a method for designing agents that interact, converse, and come to some sort of consensus about domain knowledge using verbal and non-verbal exchanges. The next stage of our effort was to apply the agent model to an immersive (man-in-the-loop) 3D training framework where the user can interact and communicate with virtual agents, experience realistic environments and stressors (cues), and engage in physical and cognitive training tasks. These training tasks—although discrete—would generate a number of highly variable outcomes due to the nature of the evolving agents.

The immersive training framework designed for this system is based on an open source technology system (Ogre3D) that runs with a middleware framework developed to generate real-time 3D scenes and manipulate objects trivially in the scene viewer. Agent states, traits, language syntax, and interaction modeling are editable features within the rapid prototype framework.

Data Collection: A data collection system provides a means to gather information about the state of the system during run-time, including agent-specific data (position, orientation, forward view, events [e.g., weapon fire], and life state and state changes). Events generated during an

exercise were given a global unique identifier (GUID) and assigned a level of severity, an instigator (culprit), location, time, and short description. Each avatar was then programmed to develop an experience of the event based on the concepts described in this paper. The event severity was used to prioritize the likelihood of it occurring in conversation. For example, a detonation (very high severity level) would certainly be a high probability conversation topic between agents within a certain time of its occurrence. Agents were designed to flee from events with high severity levels until panic levels were below the agent's panic threshold. When an agent's hostility threshold was exceeded, the agent would posture aggressively against non-factional members by visual taunting, yelling, throwing stones, and exhibiting mob-like behaviors. Agents with a high tendency towards compassion would seek out and treat any agent regardless of faction. Conversations between agents were stored/ recorded in a human readable text format, and included the knowledge (memes) shared during the exchange.

2.1 Case Study: Locate the Agent

A vignette was designed to observe the effects of a simple task training exercise in the emergent behavior framework. Participants were asked to locate two pre-selected characters—one from each faction—by finding a participant(s) who would lead them to the agents. No knowledge of faction or family relationship was known and no visual information was provided to identify the culprit by face. Each avatar uses a modified "Prisoner's Dilemma" decision-making scheme when choosing to respond to the player (Non-zero-sum game in which two players may each "cooperate" with or "defect" from [betray] the other player). In this study, the game adds an extra dimension where opposing factions can witness, or at least believe they have witnessed, betrayal or cooperation.

$$S\,(o, V_0, V_1, F, T)$$

Each agent's decision to cooperate or defect is influenced by a strategy function $\boldsymbol{S}$, where $\boldsymbol{o}$ is the set of possible locations for agent, with cognitive traits $\boldsymbol{V_0}$, societal constraints $\boldsymbol{V_1}$, perception $\boldsymbol{F}$, and desire to cooperate $\boldsymbol{T}$.

A fictional Iraqi city was generated using a 3D modeling tool; 100 virtual agents were added to the world as one of 10 visual representations of an Arabic male, an Arabic female, or a US soldier. Each agent was given a language script, an initial faction (Sunni, Shiia, and Neutral), a cooperation matrix, and a set of effector values that described the agent's overall disposition.

$$f = \left(\frac{\omega}{\upsilon}\right) \times \iota$$

A pseudo genealogy relationship was generated where simple family structure was generated with population size ω, number of family members υ, and a parameterized variation ι in size.

Family members were given a normalized value ẃ in relationship to the agent where 0 was very distant relationship and 1 was an immediate or very close family member. The same relationships were created between factional members where 0 is no relationship and 1 is very close companion. Initially, virtual agents were given 10 minutes of time for 'sense-making' activities, including participating in conversations such as:

How are you feeling?
What are your concerns?
Do you see anyone suspicious?
How do you feel about the factional issues here?
Did you talk to anyone? And what did he ask you?
Where are you going?

These initial questions provided information about other agents' well being, their whereabouts, where they were going, and what they were doing. Agents who were of dissimilar faction or not members of a family were tagged as 'suspicious' unless an agent who knew the suspicious character identified him.

The participant could move freely throughout the virtual world, including entering buildings, driving one of several military and non-military vehicles, and interacting with physical objects (e.g., carts, tents, and market stalls). The participant was allowed to greet, discuss casual information, and discuss the interest in finding the agent using the following syntax:

Do you know <Man in Question>?
How do you know him? (Are you related?)
Who else knows him?
Can you show me where he is?

Participants could conduct an interrogation anywhere and had the ability to relocate the agent to a specific location to minimize other agents' view of the conversation. Moving other agents out of the current location if observed by other agents could be negatively perceived. If the questioned agent was unresponsive, the participant was given a few methods to coerce information from him, including intimidation (surrounded by US soldiers) and arrest. Coercion made it easier to obtain information from an agent but with potentially serious repercussions, such as an increase of hostility and panic. Coercive questioning (and arrest) also had the deleterious effect of creating unrest in nearby agents of any faction. Mutation of event knowledge (misinformation) was designed as a probability function based on the agent's

weighted *Individual Rationality* design and negotiation protocols.

In summary, the algorithm is as follows:

1. Agents are given free roam to gather information through perceptual knowledge and communication with other agents.
2. Agents communicate with other agents with higher probability of interacting with similar (homophily) agents.
3. Agents could be questioned by the subject, coerced, or arrested to gather information.
4. Misperception of information might occur with a given probability either through misrepresentation or lack of complete information.

2.2 Observations

The act of finding the agents in question (the primary task) gave context for observing how a simple set of actions can evolve the balance and order of the agent population. By and large, agents of similar faction and relationship tended to associate; however, inquisitive and gregarious types tended to share knowledge more freely outside their safety areas. Members of dissimilar factions by design tended not to participate often in sharing knowledge outside of their respective associations. When asked to divulge information to the training participant, the likelihood of doing so was based primarily on the agent's mechanism design and perceptual knowledge of an event. Arrests tended to cause the greatest upheaval, especially with similar faction members, including a flurry of sharing thoughts on why the arrest happened. Events with high severity levels tended to consume conversations between agents and tended to shape malleable cognitive traits (Panic, Hostility) in the agent.

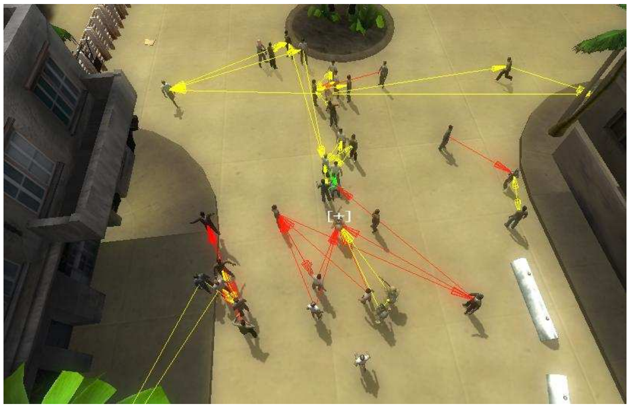

Fig. 6: Communication Interactions

Figure 6 illustrates (with a set of three colored lines) the effect of challenging then arresting an agent in full view of the population. The yellow lines represent non-aggressive interactions, the red lines show aggressive behavior directed at agents, and green lines illustrate intentional misrepresentation in communication. Aggressive posturing tended to happen often within close proximity of an arrest of an inter-factional member, and more often within full view of the event. Although agents that reached hostility levels beyond the non-aggressive threshold tended to cause more damage to the participant, this aggressive posturing tended not to permeate as quickly in the surrounding group. This was primarily because information about what was being experienced by the aggressor was not being communicated; rather, the agent simply acted out the aggression. Panic (fear) seemed to play an important role in keeping hostility levels in check. Where aggression tended to create pockets of angry agents, panic (a polarizing mechanism) kept crowds from converging, which minimized the spread of negative information.

CONCLUSIONS

We present a case for modeling certain perceptual and communication aspects of these n^{th} order effects caused primarily by the sharing of knowledge and events by virtual agents. We observed that, when two or more agents can share knowledge about events through *agreement* and continue to spread this knowledge within the social fabric, new information is added to the collective that has the effect of evolving the information available in the domain. As knowledge is pieced together, shared, and expressed through language and non-verbal communication, domain knowledge evolves through partial perception and imprecise transmission (language, gesture). Direct misrepresentation—a social mutation effect—creates new memetic information where its frequency is based on several operating parameters, including individual social welfare and negotiation protocols.

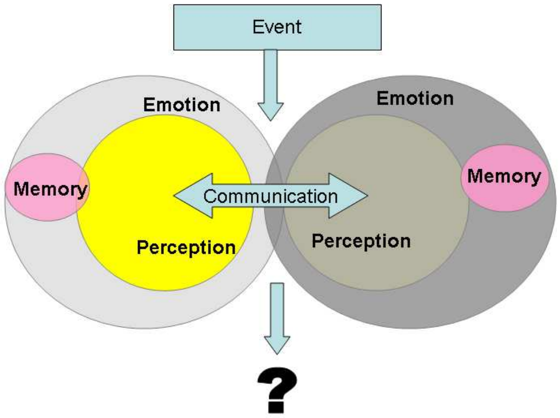

Fig. 7: Complex Agreement

Figure 7 illustrates an exchange in which two agents discuss an event with minimal overlap in perception. When there is little shared knowledge between agents about an event, we find that alternate factors become

more dominant in the decision as to what may have happened. For example, partial perception, crowd consensus, ability to enroll others' past non-related experiences (memory), and random variation play a role in determining what has happened; these exchanges (*complex agreements*) are where we see a high degree of variation between what has happened and what is perceived. Often we are asked to piece together bits of knowledge to make sense of some event, and very often we rely on the apparent good sense of the population (consensus) to help us come to some definitive answer about an event or set of circumstances. We may look to some critical level of agreement between agents that create consensus, and to what extent validity of data (proof), cultural disposition, genetics, and other factors play in determining the consensus. Ultimately, as information flows through the social network, training outcomes become less deterministic. In fact, we expect that training objectives should be measured as both basic outcomes (knowledge and comprehension, specific task completion) and higher-order outcomes (complex evaluation, cumulative awareness) if we were to consider the overall mission success.

Another aspect of our approach was to examine how immersed human participants train in and impact the adaptive and evolving social system. A great deal of social simulation research has examined the interplay of agents at a constructive level where agents roam in a world of constrained parameters and minimal human interaction. The proposed model creates a bridge between the multiagent community of emergent analysis, and social complexity with the value of immersive 3D training simulators where critical decision-making skills can be tested in realistic, cognitively and perceptually rich environments. We are exploring the proposed agent model as an addition to complex 3D social network systems where human participants can interact alongside SDEM virtual agent in persistent virtual worlds. These agents can inhabit the virtual landscapes as instructors, participants in cultural or social training exercises, or even as recruitment and retention specialists, designed to help generate balance where players may harass others or maliciously attempt disharmony. Future models will look to more adaptively rich methods of describing the cultural model in cognitive architecture models, natural language syntax, and generalized methods of encoding culture subject matter expertise into the SDEM model.

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